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Flow Measurements Through Aortocoronary and Intraluminal Coronary Shunts

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Summary

Aims. Temporary insertion of shunts during coronary artery bypass grafting (CABG) on the beating heart may provide the minimal flow required for adequate myocardial protection (40 to 60 ml/min). We investigated the flow as a function of the pressure head over three aortocoronary shunts and one intraluminal coronary shunt.

Methods. The aortocoronary shunts (VS-01590 with bulb size 2, 3 and 4 mm) and the intraluminal shunt (IVS-4030, bulb size 4 mm) were perfused with 47% glycerin solution at 37° C. The preload was raised in 5 mmHg steps from 35 to 80 mmHg. The afterload was set at 12 mmHg. A regression analysis of the flow on the pressure head was performed.

Results. For maximal preload the flow through the aortocoronary shunts was 15.9 ± 1.3, 46.2 ± 2.2 and 75.4 ± 3.3 ml/min, for the intraluminal shunt it was 76.1 ± 3.4 ml/min. To provide a flow of 40 ml/min a preload of 70, 50 and 45 mmHg was necessary for the 3 mm and 4 mm aortocoronary shunt and the intraluminal shunt respectively. For the aortocoronary and the intraluminal shunts the ß-coefficients were 0.27, 0.66, 1.13 and 1.02 ml/(min*mmHg) respectively with all $p < 0.0001$.

Conclusions. For adequate pressure head the 3 mm and 4 mm aortocoronary shunt and the intraluminal shunt provide myocardial protection. In case of severe proximal coronary stenosis the intraluminal shunt will not guarantee myocardial protection and main benefit reduces to working in a bloodless field. The insertion of shunts is a cheap and simple method to optimize CABG on the beating heart.

Keywords: Aortocoronary shunt, intraluminal coronary shunt, CABG on the beating heart, flow characteristics, distal coronary ischemia, myocardial protection

Introduction

Originally, coronary revascularization was performed on the beating heart [1, 2]. Main difficulties arose from blood at the site of arteriotomy, distal coronary ischemia, the motion of the coronary target vessel and the drop of blood pressure when lifting the heart for posterior anastomosis. Due to the development of extracorporeal circulation these problems were overcome.

The morbidity of current coronary bypass operations is mainly due to cardiopulmonary bypass (CPB) and instillation of cardioplegia which subsequently impairs left ventricular function [3, 4]. CPB is associated with coagulopathy, inflammatory response, hemodilution, renal insufficiency and stroke. The manipulation of the aorta can cause cerebral atheroembolisms. Due to these complications coronary artery bypass grafting (CABG) on the beating heart has been revitalized [5–9] thereby giving rise to the original problems of coronary revascularization.

Several devices have been designed to stabilize the target area for the anastomosis and considerably facilitate suturing on the beating heart [3]. The insertion of an aortocoronary or intraluminal coronary shunt has been proposed to avoid blood in the field

of arteriotomy and to protect against myocardial ischemia [5, 6, 10–12]. Since the use of coronary perfusion catheters during percutaneous transluminal coronary angioplasty (PTCA) has shown to prevent distal coronary ischemia during prolonged inflation [13–18] there is some evidence that the application of shunts may optimize CABG on the beating heart. The minimal coronary flow required for adequate myocardial protection is 40 to 60 ml/min depending on the mass of supplied myocard [13, 14]. It is not known whether available shunts provide a flow high enough to prevent myocardial ischemia. The purpose of this study was to measure the flow as a function of the pressure head through three aortocoronary shunts (BRMI® Vascular Shunts VS-01590) and an intraluminal coronary shunt (AnastaFLO® IVS-4030).

Methods

Shunt description. The BRMI Vascular Shunts (Baxter, Midvale, USA) are designed to shunt arterial blood around the surgical site during vascular operations. The components of these shunts are shown in Figure 1a. For CABG on the beating heart the tip is introduced in the aorta and blood flies through a PVC tubing to the arteriotomy cannula. This cannula consists of a soft polyurethane material and is introduced at the site of anastomosis. The shunts considered here (VS-01590) had a tip length of 15 mm, a tubing length of 90 cm, a cannula length of 57 mm and cannula bulb sizes of 2, 3 and 4 mm respectively. The other device investigated here is the AnastaFLO IVS-4030 (Baxter, Midvale, USA) which is shown in Figure 1b. It has a 30 mm silicon shaft, a bulb size of 4 mm and is introduced at the site of anastomosis as well. The midpoint is encircled with a retention suture for easy withdrawal after completion of the anastomosis.

In vitro setting. The in vitro setting for the Vascular Shunts is shown in Figure 2. Two fluid reservoirs were connected by plastic tubes and filled with a 47% glycerin solution. A roller pump (Stöckert, Munich, Germany) was put between reservoir two and reservoir one and a heat exchanger guaranteed a stable fluid temperature of 37° C. At the outflow site of the pump the tube was cannulated and the shunts were introduced. The glycerin solution flew through the shunts in a further expansion reservoir permitting a stable pressure of 12 mmHg at the outflow site of the shunts. From here the fluid was directed to reservoir two. The pressure at the inflow site of the shunts was changed by 5 mmHg steps from 35 to 80 mmHg by raising the height of reservoir one. The pressures at the inflow and outflow site of the shunt were controlled by two Millar pressure probes (Millar Instruments, Houston, Texas, USA) and the flow through the shunt was measured by a transit-time Doppler flow probe (Transonic Systems Inc., Ithaca, New York, USA). A similar setting was used to investigate the AnastaFLO Shunt.

Statistics. The definition of mean value and standard deviation conform to standard use. Regression analysis of the flow with respect to the pressure head (pressure head = pressure at the inflow site minus pressure at the outflow site) has been performed. A p value less than 0.05 indicated statistical significance.

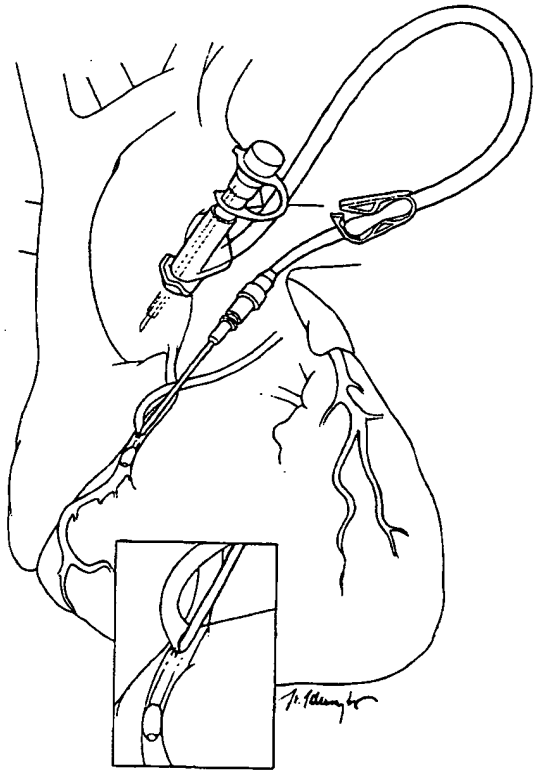

Figure 1 a. BMRI Vascular Shunt VS-01590.

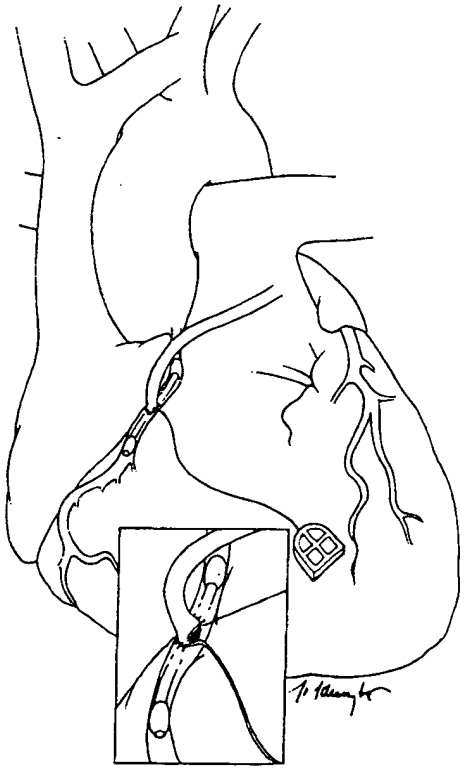

Figure 1 b. AnastaFLO IVS-4030.

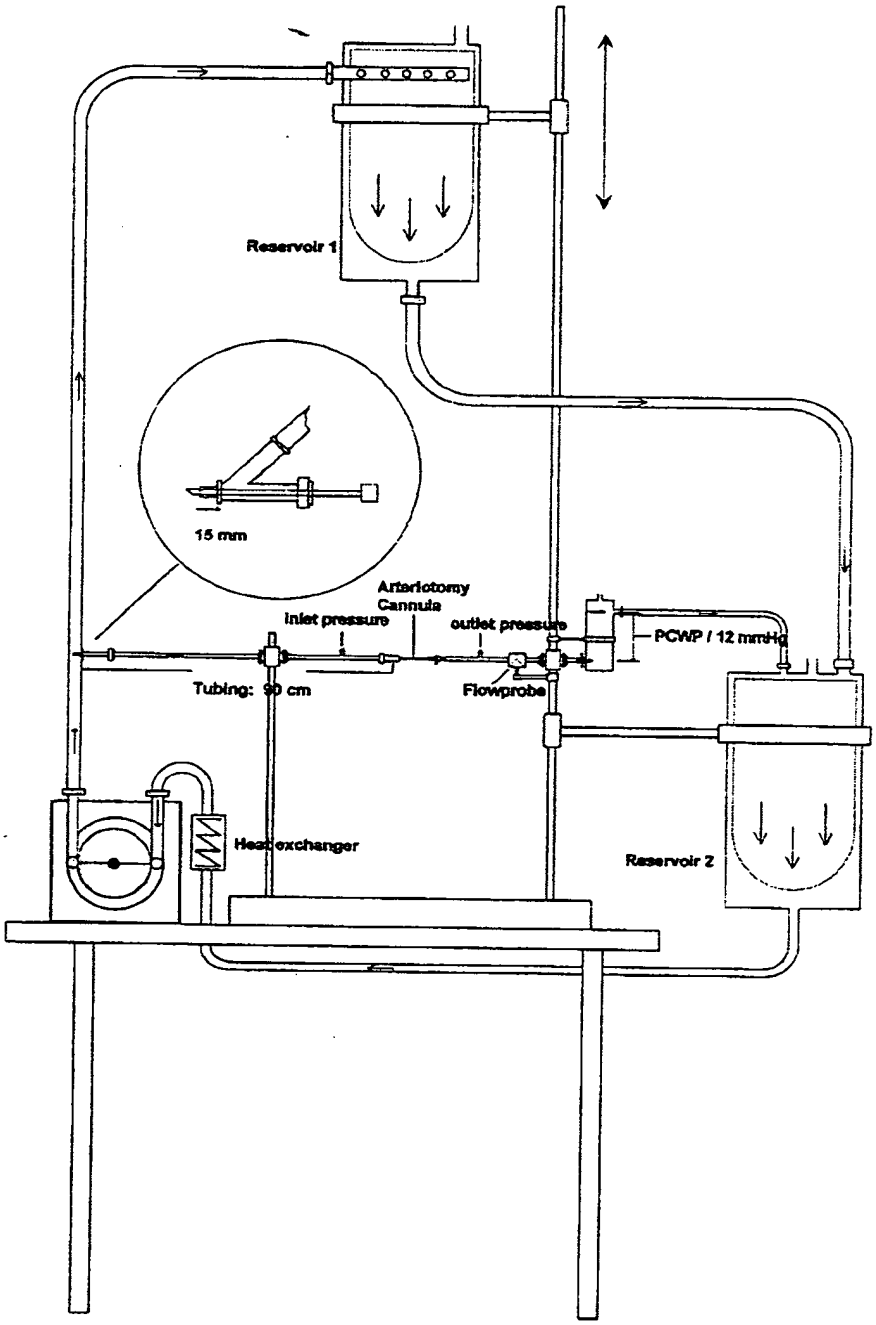

Figure 2. In vitro setting for BMRI Vascular Shunts VS-01590.

Results

Table I shows the results of the flow in relation to the pressure head for the four shunts. At a pressure head of 68 mmHg the flow through the aortocoronary shunts VS-01590 with bulb size 2, 3 and 4 mm was 15.9 ± 1.3, 46.2 ± 2.2 and 75.4 ± 3.3 ml/min respectively, for the intraluminal shunt IVS-4030 the flow was 76.1 ± 3.4 ml/min. To provide a flow of 40 ml/min a pressure head of 58, 38 and 33 mmHg was necessary for the 3 mm and 4 mm aortocoronary shunt and the IVS-4030 respectively. For all shunts a linear regression analysis showed that rising pressure head was a significant predictor for increased flow. The corresponding ß-coefficients for the aortocoronary shunts (bulb size 2, 3 and 4 mm) and IVS 4030 were 0.27, 0.66, 1.13 and 1.02 ml/(min*mmHg) respectively with all $p < 0.0001$. An illustration of the results for the aortocoronary shunts is shown in Figure 3 and for the intraluminal shunt in Figure 4 with linear interpolation between the measured mean values.

Table I. Flow in relation to pressure head.

	pressure head (mmHg)				
	23	28	33	38	43
VS-01590 bulb size 2 mm	3.8 ± 0.5	4.9 ± 0.6	6.1 ± 0.6	7.3 ± 0.7	8.4 ± 0.8
VS-01590 bulb size 3 mm	16.3 ± 1.2	19.7 ± 1.2	23.6 ± 1.4	27.4 ± 1.5	31.0 ± 1.7
VS-0 1590 bulb size 4 mm	25.2 ± 1.4	30.9 ± 1.6	36.4 ± 1.7	42.0 ± 2.0	47.8 ± 2.3
AnastaFLO IVS-4030	31.4 ± 1.5	36.5 ± 1.8	41.7 ± 2.1	46.7 ± 2.4	51.8 ± 2.6
	pressure head (mmHg)				
	48	53	58	63	68
VS-01590 bulb size 2 mm	10.0 ± 1.1	11.5 ± 1.3	13.0 ± 1.2	14.4 ± 1.3	15.9 ± 1.3
VS-01590 bulb size 3 mm	34.2 ± 1.8	37.0 ± 2.0	40.1 ± 2.1	43.1 ± 2.0	46.2 ± 2.2
VS-01590 bulb size 4 mm	53.6 ± 2.5	59.5 ± 2.9	65.2 ± 3.0	70.3 ± 3.1	75.4 ± 3.3
AnastaFLO IVS-4030	57.1 ± 2.8	62.4 ± 3.0	68.0 ± 3.3	73.5 ± 3.6	76.1 ± 3.4

Blood flow (ml/min) expressed as mean value ± standard deviation

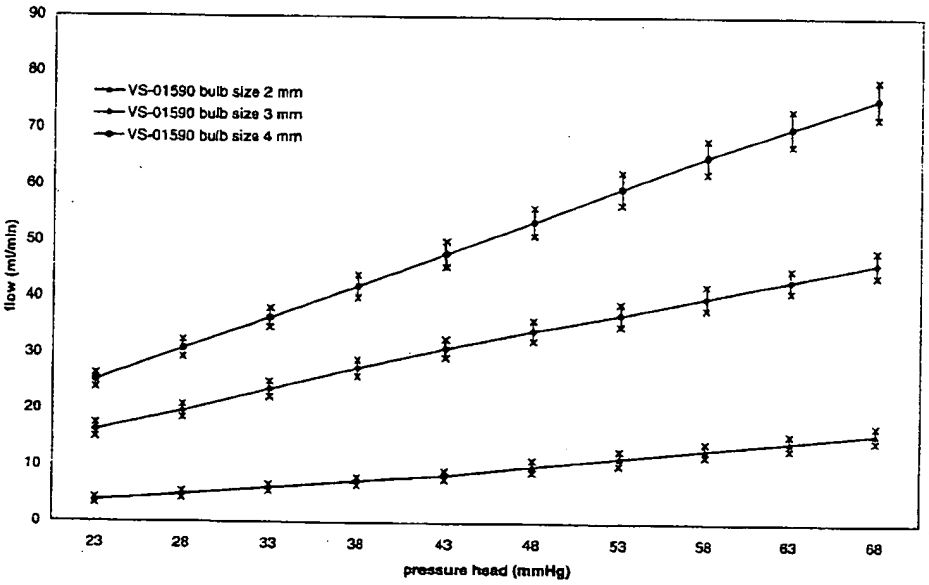

Figure 3. Flow with respect to pressure head for aortocoronary shunts.

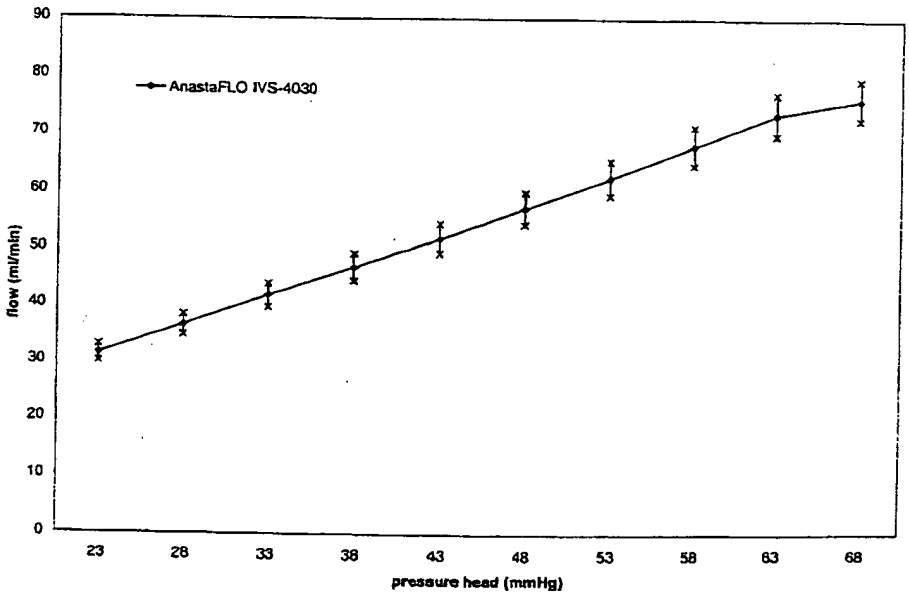

Figure 4. Flow with respect to pressure head for intraluminal shunts.

Discussion

Since cardiopulmonary bypass is the main reason for the morbidity associated with current coronary bypass operations CABG on the beating heart has been revitalized. Temporary insertion of aortocoronary or intraluminal coronary shunts has been proposed to avoid blood in the field of arteriotomy and to prevent distal coronary ischemia. There is some evidence that the application of shunts will optimize CABG on the beating heart since the use of coronary perfusion catheters during PTCA significantly diminished chest pain and ECG changes. In several studies investigating perfusion catheters it has been shown that a blood flow of 40 to 60 ml/min is enough for safe prolonged inflation. But there were no quantitative results whether available coronary shunts provide a flow high enough for myocardial protection.

There is a controversy about the estimation of the coronary perfusion pressure. Usually the perfusion pressure is calculated by taking the diastolic pressure minus the pulmonary capillary wedge pressure (PCWP). Recent models suggest to use the diastolic pressure as the pressure head for the coronary arteries. For our investigation we decided to work with the standard definition.

Our results show that the 2 mm aortocoronary shunt doesn't provide the proposed 40 ml/min in the range of pressure head that was investigated here. In case of severe stenosis the intraluminal shunt IVS-4030 will probably not supply the recommended 40 ml/min neither. The 3 mm and 4 mm aortocoronary shunts however provide adequate flow if the pressure head is high enough. Initial clinical results have shown that the use of intracoronary catheters or shunts during CABG on the beating heart prevented distal coronary ischemia in vessels down to 1.0 mm in size [5]. Furthermore the shunts permitted the precise suturing of the anastomosis in a bloodless field and no adverse effects such as arrhythmia, hypotension or trauma of the target coronary artery occurred [5, 12]. Therefore the use of all investigated shunts can be recommended. In case of severe proximal stenosis the application of an aortocoronary shunt will provide a higher flow than an intraluminal shunt.

There are some further remarks for the interpretation of our results. Blood with a normal hematocrit has a higher viscosity than the glycerin solution we used here. It will be necessary to investigate the flow for different values of the hematocrit and for changing pressure head to derive in vivo estimates for the blood flow. For the in vivo estimation the phasic nature of coronary flow and the resistance of the possibly sclerotic distal coronary bed must be taken into account. The aortocoronary shunts are also available with a tubing length of 45 cm instead of the 90 cm used in this study. The reduction of the tubing length will increase the blood flow (about 10%) but the main part of pressure drop arises in the cannula which is introduced in the coronary artery.

Conclusively, our in vitro measurements as well as initial clinical results confirm the hypothesis that temporary insertion of coronary shunts is a cheap and simple method to optimize CABG on the beating heart.

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